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STEREO PHOTOGRAPHY OF THE ECHO II BALLOONS NUMBERS 9, 11, AND 13

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GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

ABSTRACT

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A description is given of the equipment and technique used to determine the deviation from sphericity of the skin of three Echo II balloon satellites at varying skin pressures. Diagrams and photographs illustrate the instrumental setup and the results of the stereophotography.

Author

STEREO PHOTOGRAPHY OF THE ECHO II BALLOONS
NUMBERS 9, 11, and 13

at

Lakehurst, New Jersey

by

Sol H. Genatt

1. Requirements of Project:

The Echo Project presented the Optical Systems Branch with certain requirements when the Branch was asked to participate in the test inflations of the 135 foot diameter Echo II balloon satellites at Lakehurst, New Jersey. These requirements were as follows:

a) Areas on the balloon surface were to be photographed in stereo fashion for the purpose of measuring irregularities in the surface contour. The accuracy required was $\pm$ 1/16 inch.

b) The number of areas on each balloon to be photographed were three in number and the center of each was located approximately ten to eleven degrees south of the equator of the balloons.

c) The size of each area to be photographed was to be approximately ten feet along a parallel of latitude at the center of the area and at least six to seven feet along the central meridian.

d) x, y, z, coordinates of points along a parallel of latitude passing near the center of the area were required. These points were to be approximately three inches apart on the surface of the balloon while the coordinates were to be referred to a mean established datum plane. Accuracy of the coordinates was to be held to $\pm$ 1/16 inch.

e) A topographic contouring was required covering each of the photographed areas. The contour lines were to be spaced 1/8 inch apart with an accuracy as mentioned in 1 a.

f) All the above work was to be performed at each of several different skin pressures to which each balloon was to be inflated and at a relaxed state at each of the pressures.

g) The resultant data was to be presented in two forms:

(1) Contour lines representing each photographed area were to be shown on charts at a scale of approximately 1/5th the original size.

(2) Profile coordinate measurements were to be presented both in the form of a listing and superimposed upon a separate profile chart.

2. Photographic Equipment Used in Test Inflations:

The cameras selected to perform the stereo photography were the Wild RC8 cameras with the six inch Aviogon lenses. These cameras were selected on the basis of being the most suited for this application, both from an optical viewpoint and from a reduction capability standpoint. Picture size is 9 x 9 inches.

As normally used in aircraft, the cameras take a series of vertical photographs of objects on the ground. In this type of work, the distances between cameras and objects are considered to be infinity as far as the lens system is concerned. At Lakehurst, New Jersey, the distances between cameras and balloon surfaces were to be on the order of 13 feet. In order to record images on the balloon surface in sharp detail in the focal plane, the cameras had to be modified by increasing slightly the distance between the optical system and the emulsion side of the film. The task of modification was performed by the Wild Heerbrugg Company's office in Port Washington, New York. New calibrated focal lengths for the two cameras were as follows: 158.13mm and 159.83mm.

Superimposed on each frame taken by the cameras is the following data:

a) Fiducial marks in each corner of the frame.

b) The setting of a level bubble.

c) The picture face of a timing clock.

d) An altimeter reading.

e) A camera number identification.

f) The focal length of the camera.

g) A counter number to identify a particular frame.

The film used in the cameras for the test was Dupont, Cronar, High Contrast, Fine Grain, Type 140. It had an ASA rating of 64 and came packaged in 200 foot rolls, 9½ inches wide.

Auxiliary Equipment Used in Photography:

In the dirigible hangar at Lakehurst, New Jersey, where the tests were held, a special scaffolding was constructed to support the two cameras plus the operating personnel. Figure 1. The top of the scaffolding consisted of three connected parts. Each part which was to be a separate camera station was a level plywood platform measuring approximately 8 by 16 feet. Looking down upon the camera stations from above, they presented the appearance as in Figure 2.

During the tests, the balloon was to be suspended from the ceiling of the hangar with its polar axis vertical and its south pole six feet above the floor of the hangar.

As mentioned earlier, the RC8 cameras are normally used suspended vertically with their lens cones pointing straight down. In the tests at Lakehurst, they were to be employed with their lens cones elevated above the horizontal so that they looked perpendicularly at an area on the balloons 10° - 11° below the equator. Figure 3. This necessitated designing and constructing large, portable, aluminum dollies to hold the cameras pointing rigidly in the desired direction and with the ability to move freely in any direction.

Each dolly supported its camera so that the focal plane was approximately two feet above the bottoms of the wheels of the dolly. A scaffolding was built with platforms approximately 56 feet above the floor of the hangar. The dollies moved upon this platform and the geometry of the situation was as represented by Figure 4.

RC8 cameras with Aviogon lenses are normally used under what photogrammetrists refer to as a 0.6 base/height ratio. This means that the horizontal distance between the two cameras' exposure stations is usually 60% of the vertical distance between the midpoint of the stations, and the ground. Since the Wild Company modified the cameras to photograph in sharp detail objects 12.9 feet from the cameras, the distance between the two cameras approximated 7.74 feet. It was found in practice that the tolerance on the 12.9 feet for sharp detail was $\pm$ 5 inches.

The Aviogon f/5.6 lens used in the cameras has a field of view of 90°. Spaced 7.74 feet apart, the cameras photographed an area that was common to both of 10.8 feet along a parallel of latitude and 18 feet along a central meridian as seen in Figure 5.

If the cameras had been mounted so that they were both in a vertical plane instead of in a horizontal plane, then the area common to both would have been rotated 90° and the two measurements quoted would have been reversed as far as meridians and parallels go.

When all the equipment necessary to take the photographs had been assembled at a camera station, the layout as seen from above was as diagramed in Figure 6.

Included in the equipment were the following items:

a) A Royal Projector machine which projected upon the surface of the balloon the Army Map Service "Distorted Surface Pattern", which consisted of approximately 5,000 irregularly spaced dots. This grid was upon a 10 inch square piece of glass (positive). During use, the bulb in the projector was operated at 130 volts.

b) Camera vacuum pumps which provided suction behind the focal plane frame so that the film laid perfectly flat while the exposure was made.

c) Camera intervalometer or control boxes which governed the exposure times of the shutters and permitted either manual or automatic operation of the cameras. In use, the exposure times averaged 1/90 second and the exposures were all taken manually with one operator attending each camera.

d) Two surveyors leveling rods, each four meters long, were suspended approximately 4-5 inches from the surface of the balloon. The marks on each rod faced the camera stations and were used to introduce vertical control into the resulting photographs. Both rods were held by booms extending out from posts in the corners of the camera stations. A yardstick was suspended between the two meter sticks to introduce horizontal control into the photography. Figure 7.

e) It was found that when the photography was performed at night, auxiliary lighting upon the surface of the balloon was required to light up the dot images. This was provided by two 150 watt spotlight bulbs connected to the front of each station. During daylight photography, these bulbs were unnecessary as windows in the hangar walls allowed in sufficient sunlight to illuminate the dot images plus the photographed area.

3. Procedures, Prior, During, and Following Each Test Inflation:

Echo balloons numbers 9 and 11 were each photographed at four different skin pressures, including a relaxed condition at each pressure before they each burst. Balloon number 13 was photographed at one additional higher skin pressure than the other two before it burst.

The procedure followed at each camera station prior to the first test was as follows:

a) A thin, flat, glass plate was inserted into the focal plane of each camera. The sides of the two dollies were then set parallel to each other and the camera centers separated by 7.74 feet.

b) Previous to a), the balloon had been stationed in its position, which it was to occupy during the tests.

c) The projector was then switched on throwing the grid pattern upon the balloon surface.

d) Images of the balloon surface with the dot pattern upon it plus the meter rod markings were then examined on the glass surface in the focal plane with high power eyepieces. This inspection determined the best placing of the cameras on the platforms to give sharp detailed images. At the same time, the illumination was adjusted to minimize "hot spots" or local reflections of the bulbs' light from the skin surface and to achieve nearly uniform lighting over the entire photographed area.

e) Black paint marks were then laid on the plywood platform around each of the four wheels of each dolly to insure replacing the cameras in correct position after they had been moved from one station to another.

f) Exposures at each camera were taken manually by the two operators who watched each other so that the two members of the pair of photos were taken within ¼ second of each other. In this ¼ second interval, there was no noticeable movement of the balloon proper to cause distortion in the resulting photography.

g) A total of five exposures at each camera station at each skin pressure were taken. This was done so that a choice could be had in deciding which pair of photos should be reduced. Because the balloon moved slightly in most cases between exposures, this safeguard was taken to insure at least one sharply focused pair. As it turned out, at least three or four pairs in each set of five were in sharp focus.

h) After all testing at the various pressures had been completed, the film was processed in the photo labs of the Navy at the Lakehurst Facility. It was developed in DK50 solution with an extended developing time. After developing, a portable air drier was used to dry the film.

i) Approximately three hours after developing had begun, the film was ready to inspect. A standard light table was used here with a low power eyepiece. First, the film roll from one camera was inspected for clarity of detail and the best of the five frames was selected at each station for each pressure. Next, the roll from the other camera was inspected and the corresponding photo to complete the pair was indicated with markings and notations in the border of the frame. These markings enabled the personnel at the U. S. Army Map Service to know which pair of photos at each pressure level was to be reduced.

4. Reduction of Photos:

When the pairs of successful photographs arrived at the U. S. Army Map Service, they were put through a standard reduction process. This was the process normally followed with aerial photography from which contour mapping of various areas was desired. It consisted of first making for each pair of photos to be reduced a pair of diapositives. In this process, the detail on the photographic negatives is printed onto a super-flat glass plate, 0.250 inches thick and of the same outer dimensions as the negative. The process is characterized by introducing in the transfer the minimum possible dimensional change and at the same time the sharpest detail. It is the process preferred for all high-order mapping tasks.

The transfer for the film took place in a Wild U3-A Modified Diapositive Printer machine. Figure 8. This machine which is essentially a reducing camera of the highest precision was created in order to make it possible in photogrammetric practice for photographs from all usual surveying cameras to be used in any desired plotting machine. The printer allows the negatives to be transformed in such a manner that the dimensions and focal lengths of the diapositives produced correspond to the ranges and optical-geometrical requirements of the plotting machines which are later used to contour the photographs.

Additional functions performed by the above plotter are distortion compensation, addition of the principal point, and automatic dodging.

a) By the employment of distortion compensating plates to account for any distortion introduced in the original photography, the optical system of the printer introduces a calculated distortion such that the resultant distortion of camera, printer, and plotter combined is zero.

b) The principal point of the photograph appears as a small cross or circle on the diapositive as a result of the operator aligning the fiducial marks appearing on the film with collimating lines in the printer before an exposure is made.

c) In order to tone down hard contrasts when printing, the U3-A has a built-in automatic electronic contrasting or dodging Cintel unit. This device makes it possible to even up the image density across the entire plate and eases the task of the operator who examines the plates for contouring by eliminating practically all glare on the plates.

5. Stereoscopic Parallax:

In order to understand how the projection plotters used in photogrammetry permit contouring to be accomplished, it may be well to illustrate how the elevation of a single point on a pair of stereoscopic films is determined. The reason for this is that the stereoplanigraph machine when properly set up and oriented and made parallax free, accomplishes automatically and continuously what an operator performs in the measurement of a single point. The following paragraphs are from "Manual of Photogrammetry" by the American Society of Photogrammetry.

"One may define stereoscopic parallax as a measurable linear distance composed of line segments on each of two photographs of the same object taken from different camera stations. It is a linear element that is associated with the distances from the camera stations to the object, the separation of the camera stations, and the focal lengths of the cameras. Difference in parallax, or parallax difference, is caused by the difference in the distances from two objects to the pair of camera stations. Parallax difference in vertical aerial photographs is directly related to the relief displacements on the two photographs. Parallax difference is the principal cause of the perception of depth obtained by looking at one of a pair of photographs with each eye. Parallax difference is the element that is used to determine elevations of objects and to draw contour lines with aerial photographs by means of stereoscopic instruments.

In Figure 9, two truly vertical photographs of equal focal length f are shown a distance $OO'=B$ apart and at an altitude H above a horizontal reference plane. An object A has an elevation h and images of A occur at a on the left photograph and at a' on the right one. An x-axis is adopted on each photograph parallel to OO', and n and n' are both the principal points and nadir points of the respective photographs. The ordinates aa_1 and $a'a'_1$ are perpendicular to the x-axis. Triangle $OO'A_1$ is in the vertical plane that contains the two perspective centers (camera stations). AA_1 is perpendicular to plane $OO'A_1$, and the elevation of A_1 is also h. The absolute stereoscopic parallax of A is defined as the algebraic difference of the abscissas na_1 and $n'a'_1$.

$$p = x - x'$$

The elements are illustrated graphically in the smaller figure which is composed of triangle Oa_1n of the left photograph and triangle $O'a_1'n'$ of the right one. From similar triangles we have,

$$\frac{p}{f} = \frac{B}{H-h} \qquad (1)$$

$$h = H - \frac{Bf}{p} \qquad (2)$$

The foregoing equations serve principally to define stereoscopic parallax but parallax difference is used to determine elevations. Differentiating the above formulae, we get,

$$\Delta h = \frac{\Delta p(H-h_1)}{p_1 + \Delta p}$$

$$\Delta p = \frac{\Delta h p_1}{(H-h_1) - \Delta h}$$

h_1 is the elevation of the lower of two objects, and p_1 is the parallax of the lower point according to equation (1)."

In the photogrammetry performed for the Echo II photography, the values of f were known to the nearest ten microns, while B was kept within $\pm$ one inch of a measured value. H approximated 12.9 feet $\pm$ 5 inches, while p was measured to the nearest micron on each diapositive. For determining linear and vertical scale in the diapositives, a knowledge of the above values of f, B, and H was used in addition to the markings of the meter rods and yardstick superimposed on the balloon surface. For balloons 9 and 11, an additional feature used to obtain scale values was the almost constant length of a gore distance along the 11° parallel. For balloon number 13, markings in the form of small crosses placed on the balloon surface shortly after construction of the balloon, provided linear and horizontal scales. These markings were spaced across the area to be photographed at a distance of every three inches in both a parallel of latitude direction and a longitude direction. They were placed in this manner because of the experience gained in the reduction of balloons 9 and 11 which preceded 13. This one step greatly eased the problems of the operator in determining scale on the photographs and would be a recommended procedure in any future similar work.

The plotting machine used to reduce all the photography was the Zeiss C-8 Stereoplanograph. Figure 10. This machine, which is considered to be the most precise stereoscopic plotting instrument built, is designed to do contouring at an interval of 1/1250, or it has a C-factor capability of 1/1250. Experience at A. M. S. has shown that it can accurately contour at a C-factor of 1/1500.

In the United States, vertical error in mapping is commonly expressed as a C-factor, this being the ratio of contour interval to flying height at which 90 per cent of all points are accurate to within one-half the contour interval, and all points are accurate to within one contour interval. In the stereophotography performed at Lakehurst, the flying height equivalent was approximately 13 feet or 156 inches. Since the C-factor used at A. M. S. in this job was 1/1500, we can determine the minimum contour interval that the planograph is capable of accurately handling by,

$$\frac{\text{Flying Height}}{\text{C-factor}} = \text{Contour Interval}$$

or

$$\frac{\text{Flying Height}}{\text{Contour Interval}} = \text{C-factor}$$

or

$$\frac{156}{\text{C.I.}} = 1500$$

$$\text{Contour Interval} \cong 1/10 \text{ inches}$$

Since the contour interval requirement presented by the Echo Project was for it to be 1/8 inch and the stereoplanograph used to do the contouring had the proven capability of doing accurate contouring at 1/10 inch intervals, at the distances used in the Echo Project, all reduction was being performed well within the capabilities of the instrument.

Quoting again from the "Manual of Photogrammetry", "the basic idea of the stereoplanograph is a reversal of the process employed in making the photographs. In photography, the rays of light from the landscape produce pictures in the camera, whereas in the stereoplanograph they are reversed and pass from the picture to the outside through lenses to form a model of the landscape. The cone of light rays originally entering the camera are reprojected in two projectors in the instrument so as to recover the conditions existing in nature at the time of the original exposures. The light rays from the projectors intersect in space to form a spacial model. This spacial model is viewed stereoscopically through a binocular optical system containing floating or measuring marks with which measurements can be made. The measuring marks are moved relative to the projectors and the model by means of a three dimensional cross-slide system, and the movements in the plane representing the ground plan are transferred to the coordinatograph machine where the compilation of all measurements is made."

For the x, y, z, profile measurements across each area of the balloon photographed at each station, the origin of the coordinate system was always taken to be a corner of a grid pattern on the balloon surface in the photographed area. Figure 7. This corner was always given the coordinates of (0,0,100.000) and was the point to which all z coordinates were referred.

After setting the machine on this point, a new setting was inserted into the machine for a z coordinate of 100.125 inches. The operator then looking into the machine no longer saw the floating dot mark tangent to the balloon surface but instead saw it either imbedded inside the balloon or suspended in space above it. By turning hand wheels, he could then bring back or move the floating dot so that it was tangent to the balloon surface at all points which had z values 1/8 inch greater than the previous setting. As he did this, a contour line of 1/8 inch interval was automatically drawn out on the coordinatograph machine at the desired scale.

Figure 11 shows a profile measurement obtained at a relaxed condition of a 4800 p.s.i. inflation pressure. These pressures are along the surface and not perpendicular to it. The figures printed along the profile indicate in inches the z coordinate of the center of the small crosses imprinted on the balloon surface and running along a parallel of latitude. The values are with regard to a point chosen near the edge of the profile and arbitrarily given a z value of 0.00.

Figures 12 and 13 show the contouring of the same area on the balloon surface at two different pressures, namely, 4800 p.s.i. and 7400 p.s.i., both at relaxed conditions. As the pressure increased from the smaller to the larger value, it is evident how many of the wrinkles disappeared from the skin surface and how a more spherical shape developed.

Acknowledgements:

The author wishes to thank the U. S. Geological Survey and the U. S. Naval Bureau of Weapons for their respective loans, each of a Wild RC-8 camera to the Goddard Space Flight Center for this test; also the Messrs. R. W. Underwood, L. L. Vance, H. L. Currie, and D. E. Leonardo of the U. S. Army Map Service for their assistance in obtaining and processing the photography at Lakehurst, New Jersey.

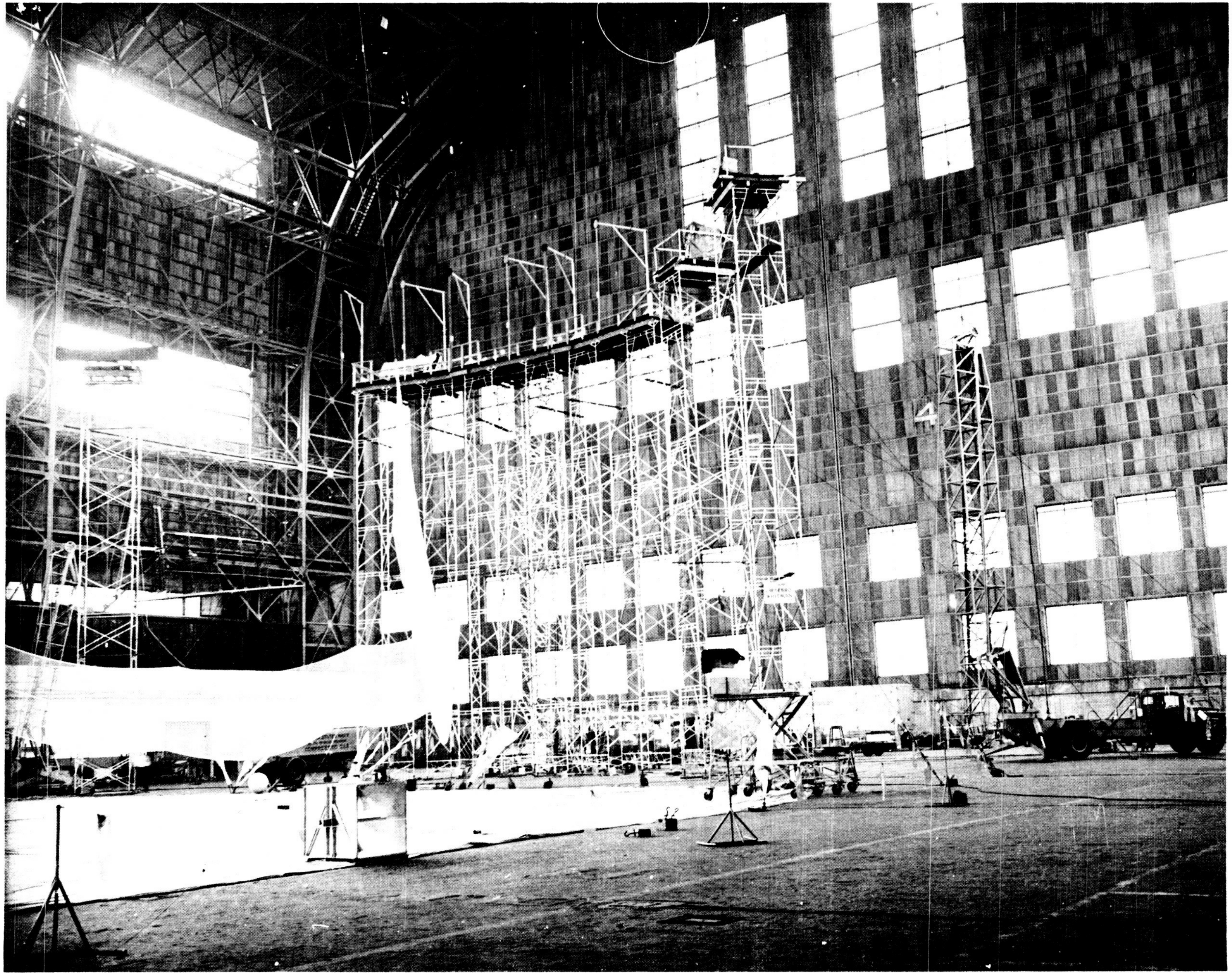


FIGURE 1

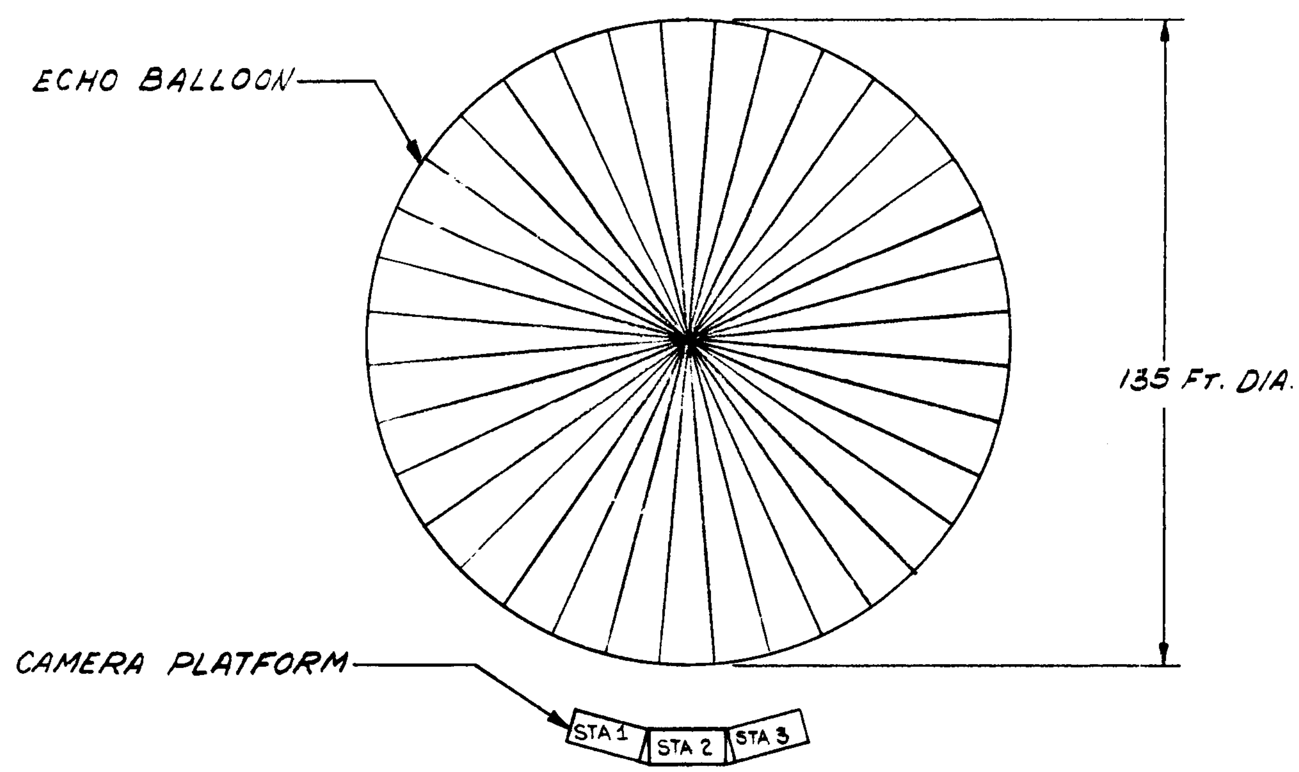


FIGURE 2

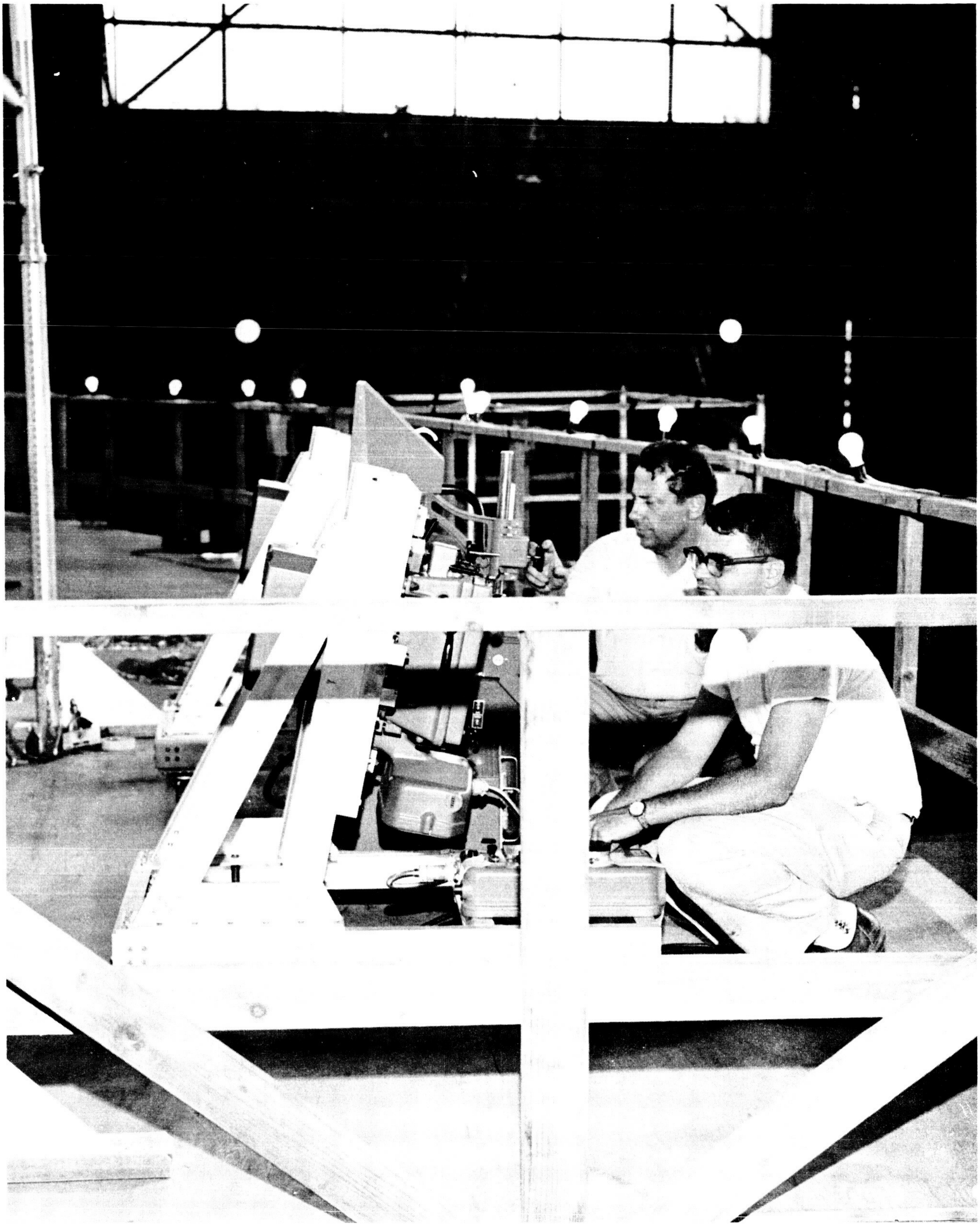
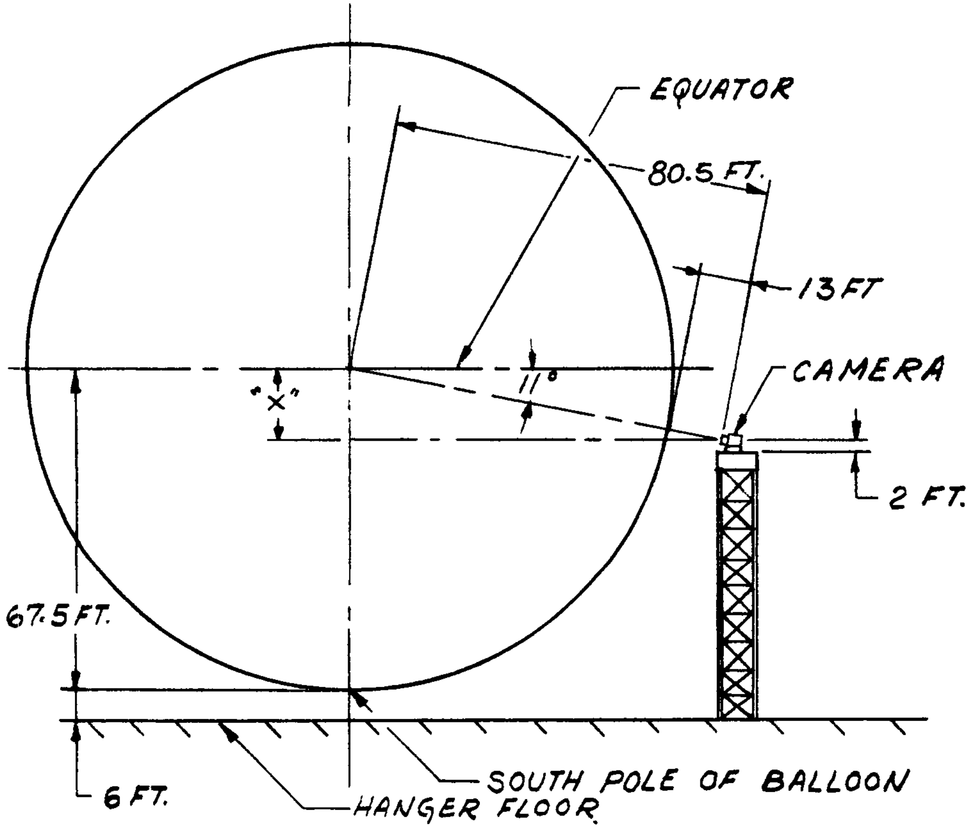


FIGURE 3



$$\sin 11^\circ = \frac{X}{80.5 \text{ FT.}}$$

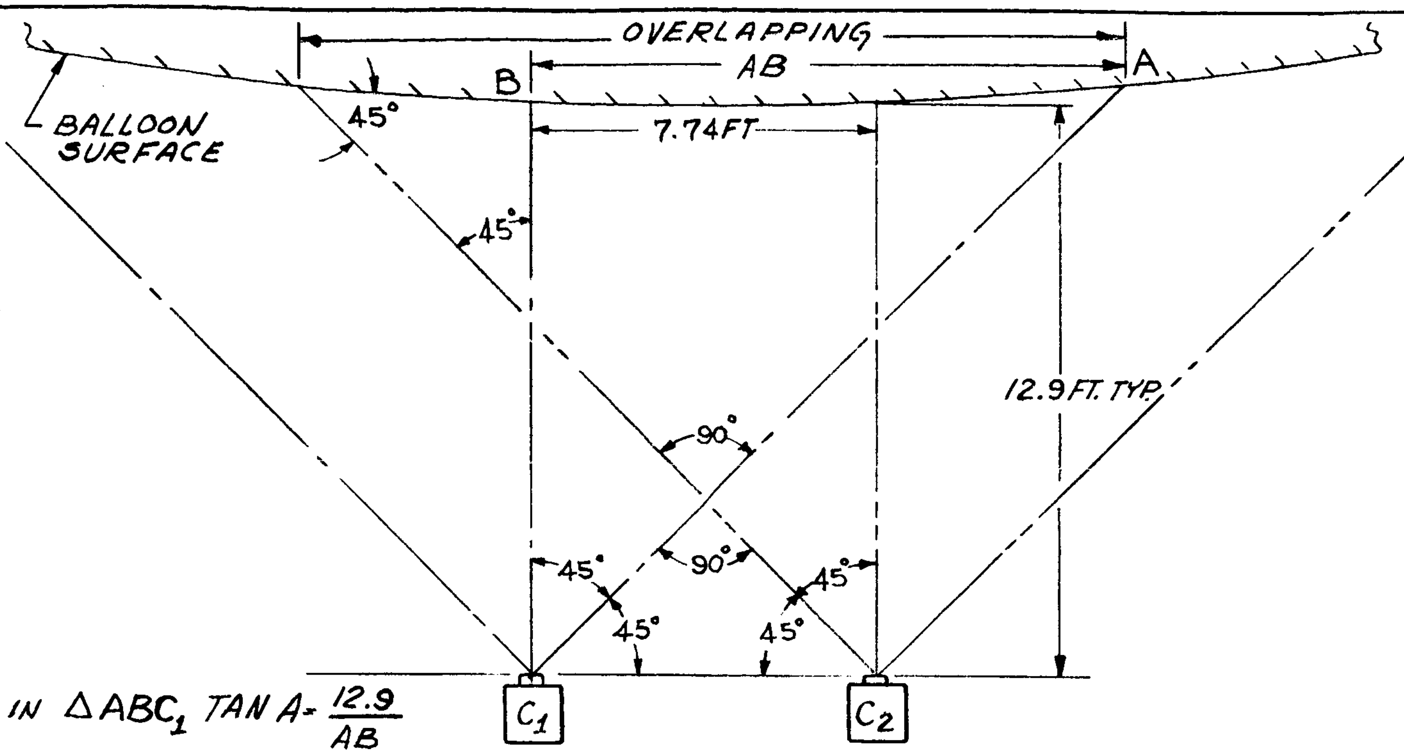
$$X = 80.5\,(.1908)$$

$$X = 15.4 \text{ FT.}$$

$$73.5 - (15.4 + 2) \cong 56$$

FIGURE 4

CR



$$\text{IN } \Delta ABC_1 \ \ \tan A = \frac{12.9}{AB}$$

$$\overline{AB} = \frac{12.9}{\tan 45^\circ}$$

$$\overline{AB} = 12.9$$

FIGURE 5

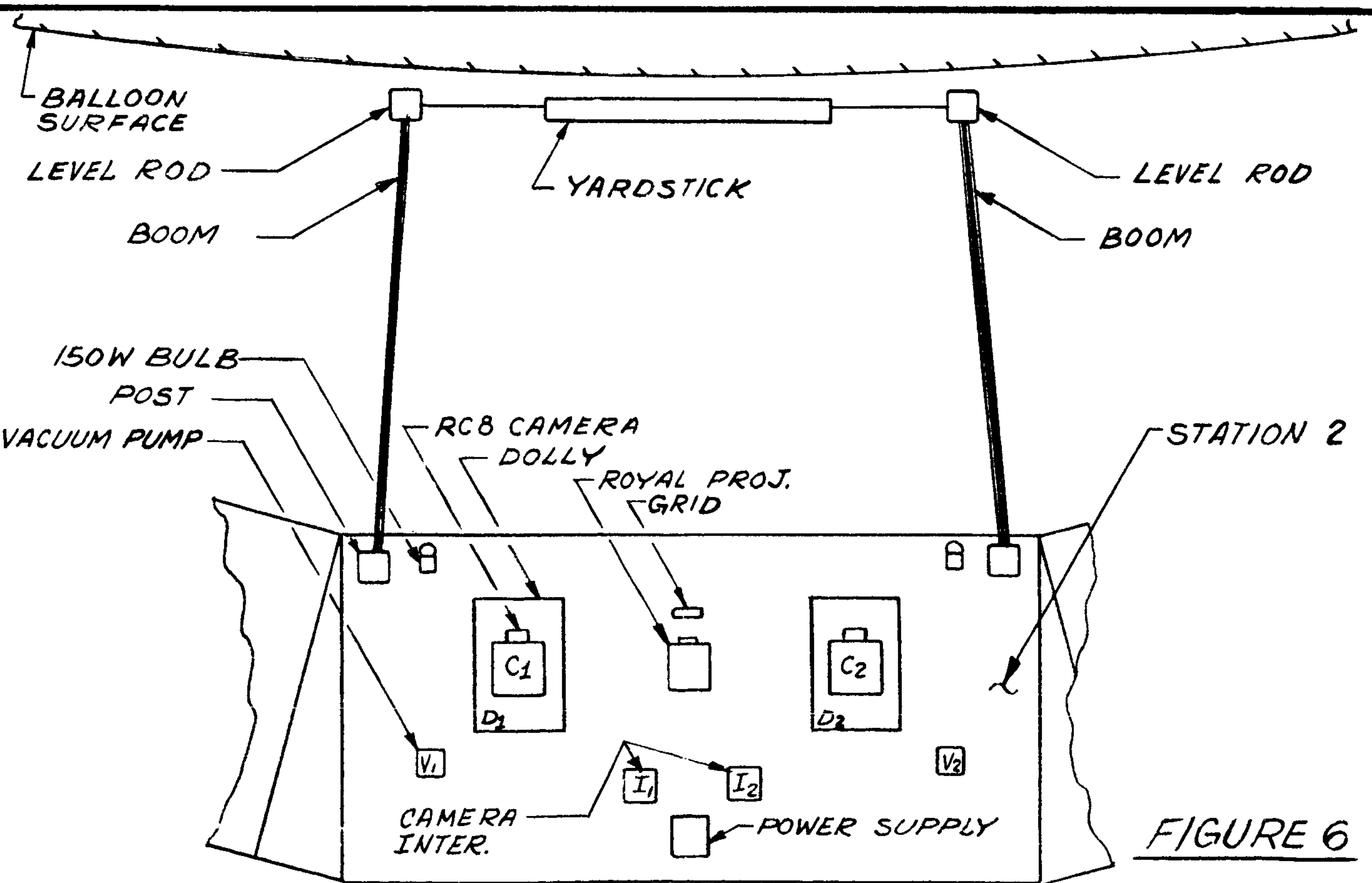


FIGURE 6

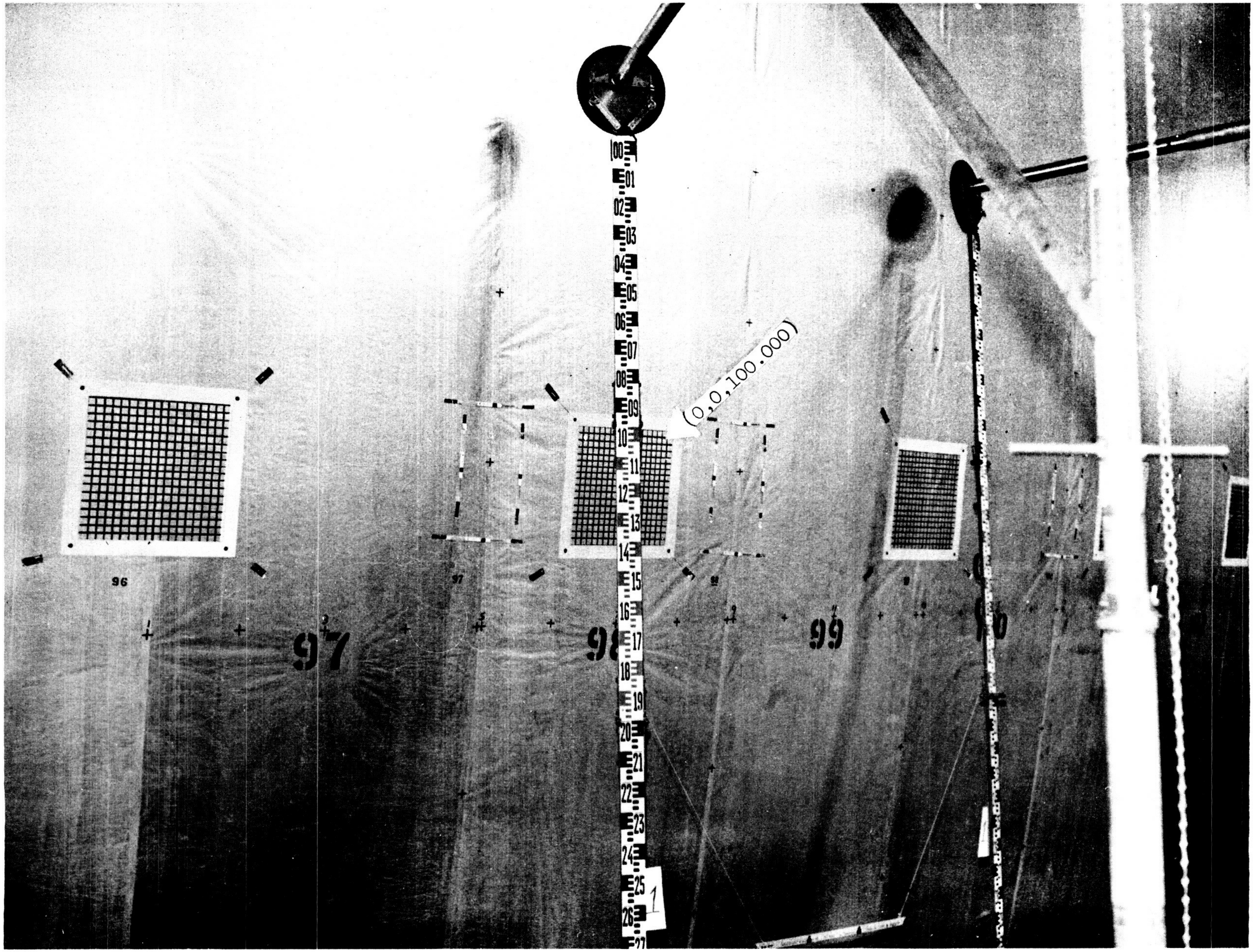
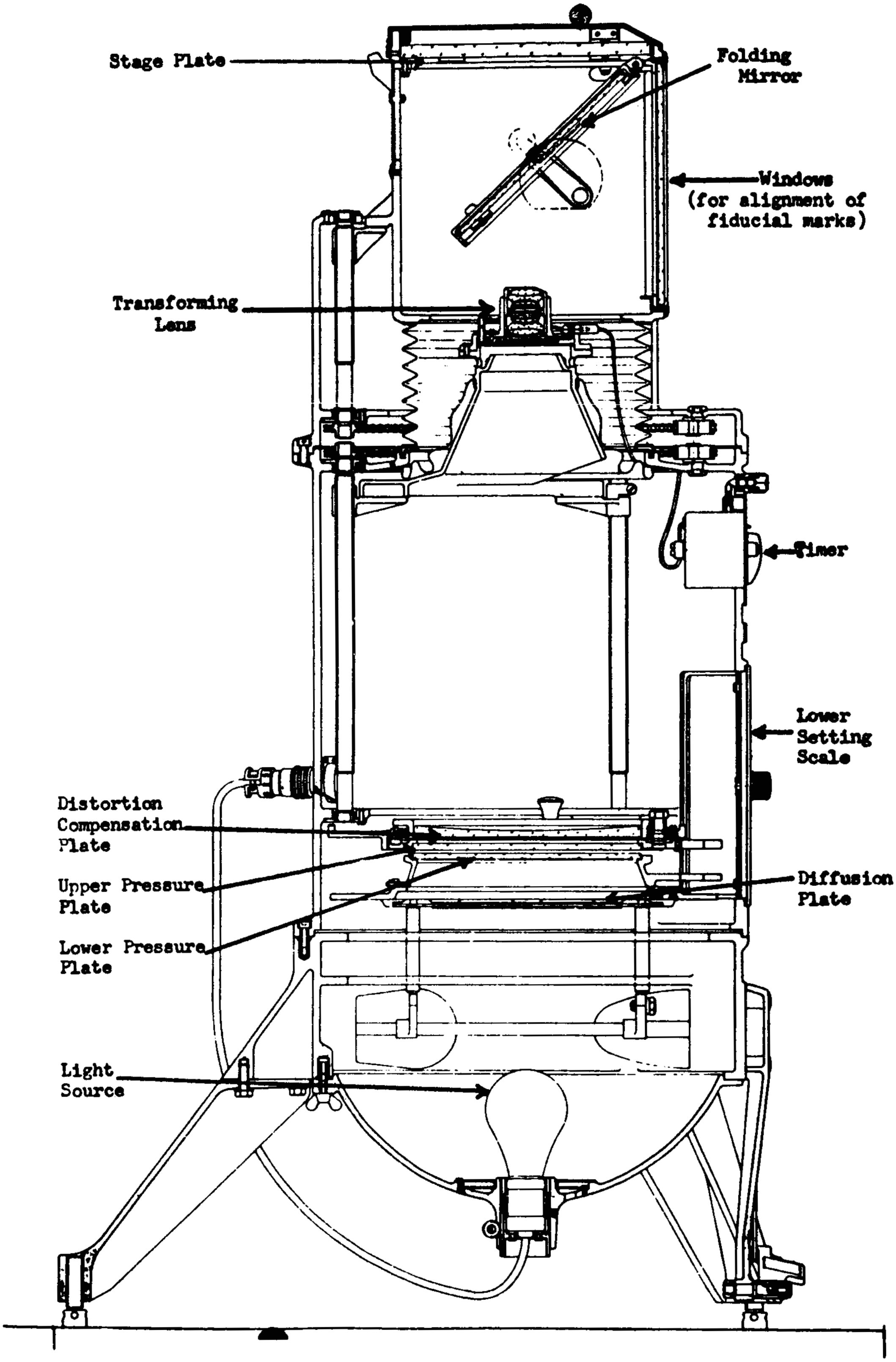
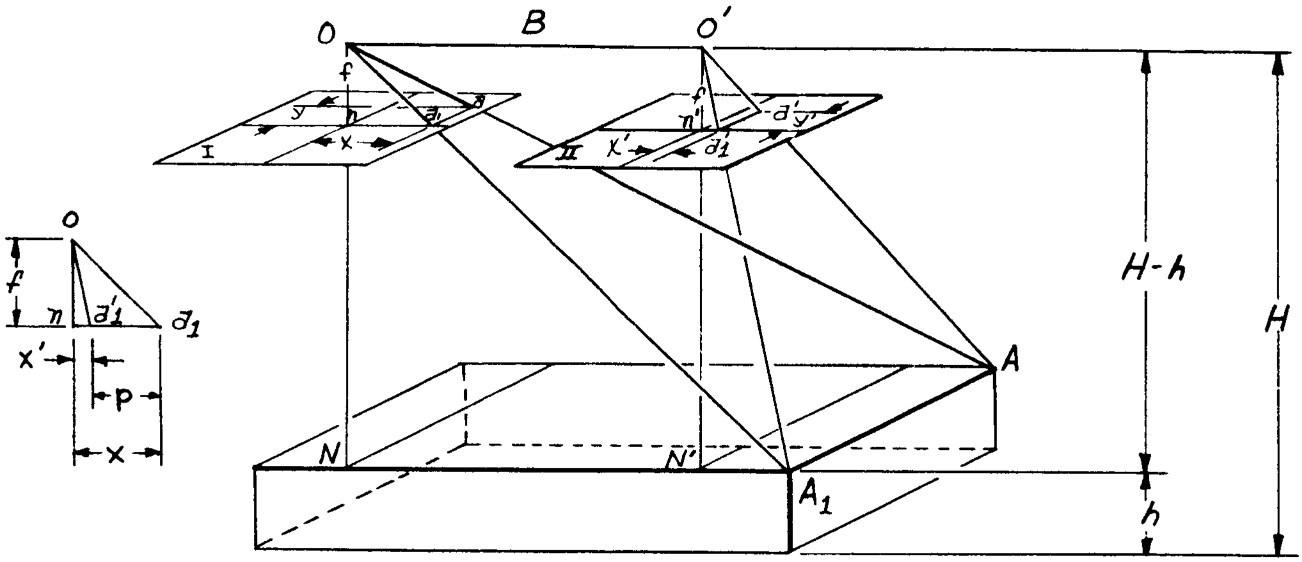


FIGURE 7



Wild U-3 Printer, Type A

FIGURE 8



STEREOSCOPIC PARALLAX
REF. MANUAL OF PHOTOGRAMMETRY PP 325
(AMER. SOC. OF PHOTOGRAMMETRY)

FIGURE 9

CR

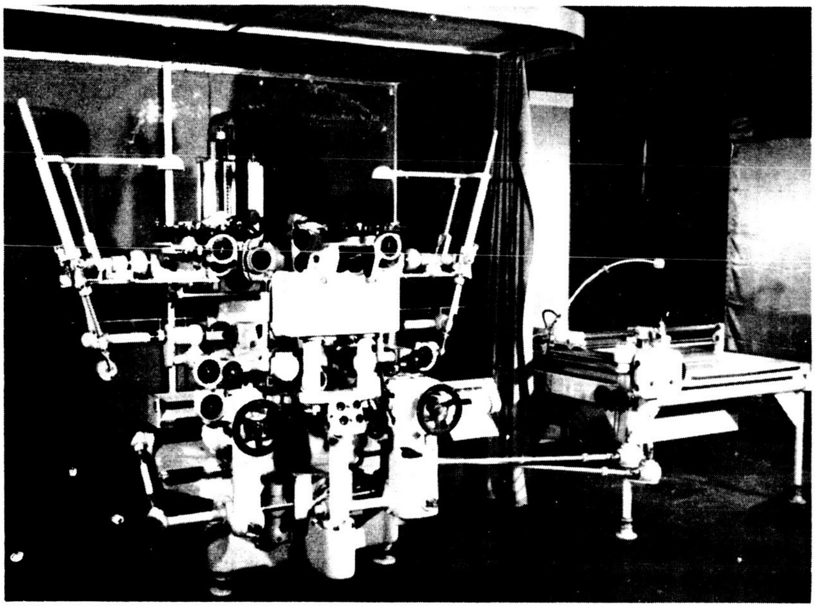
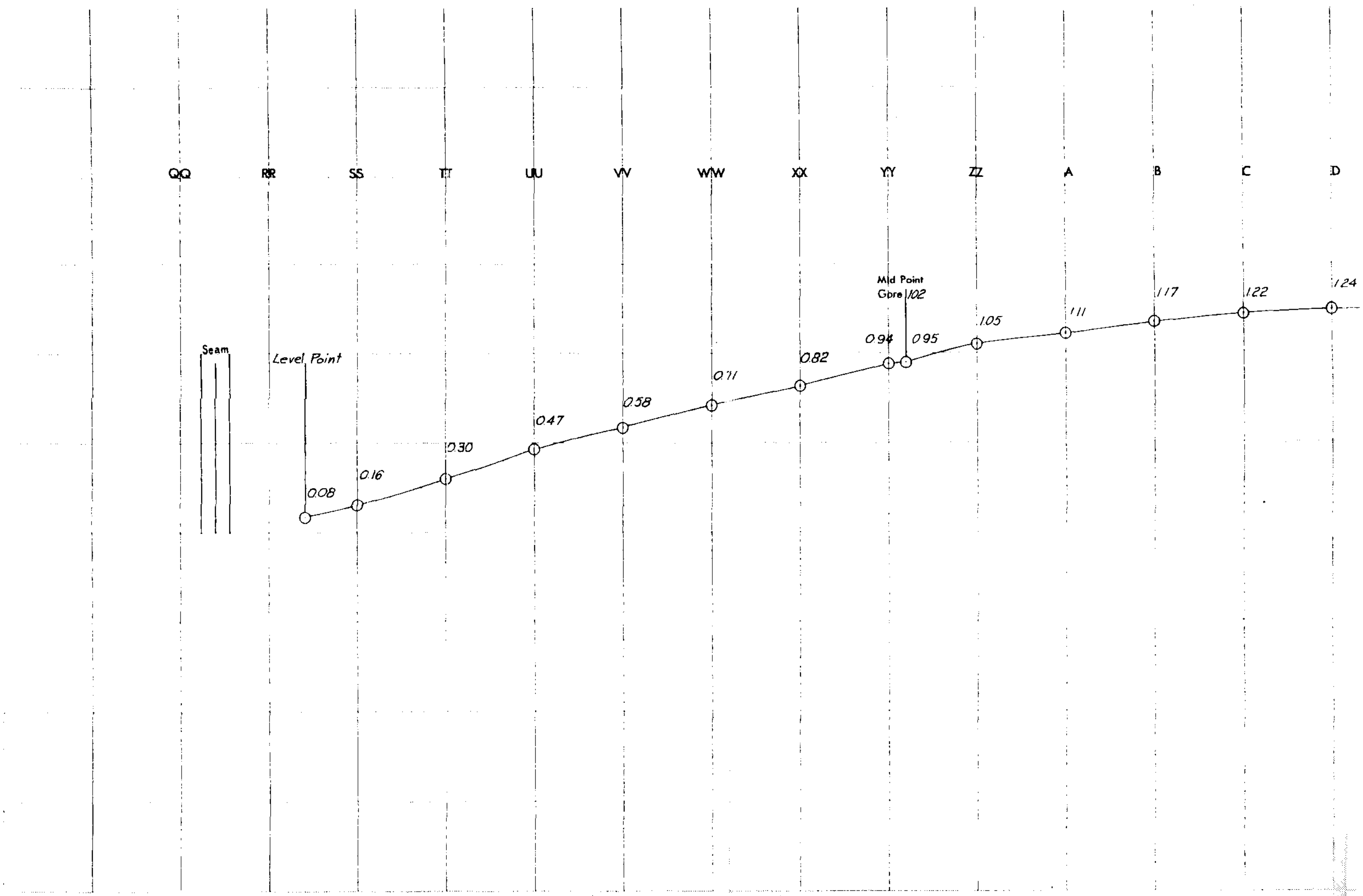
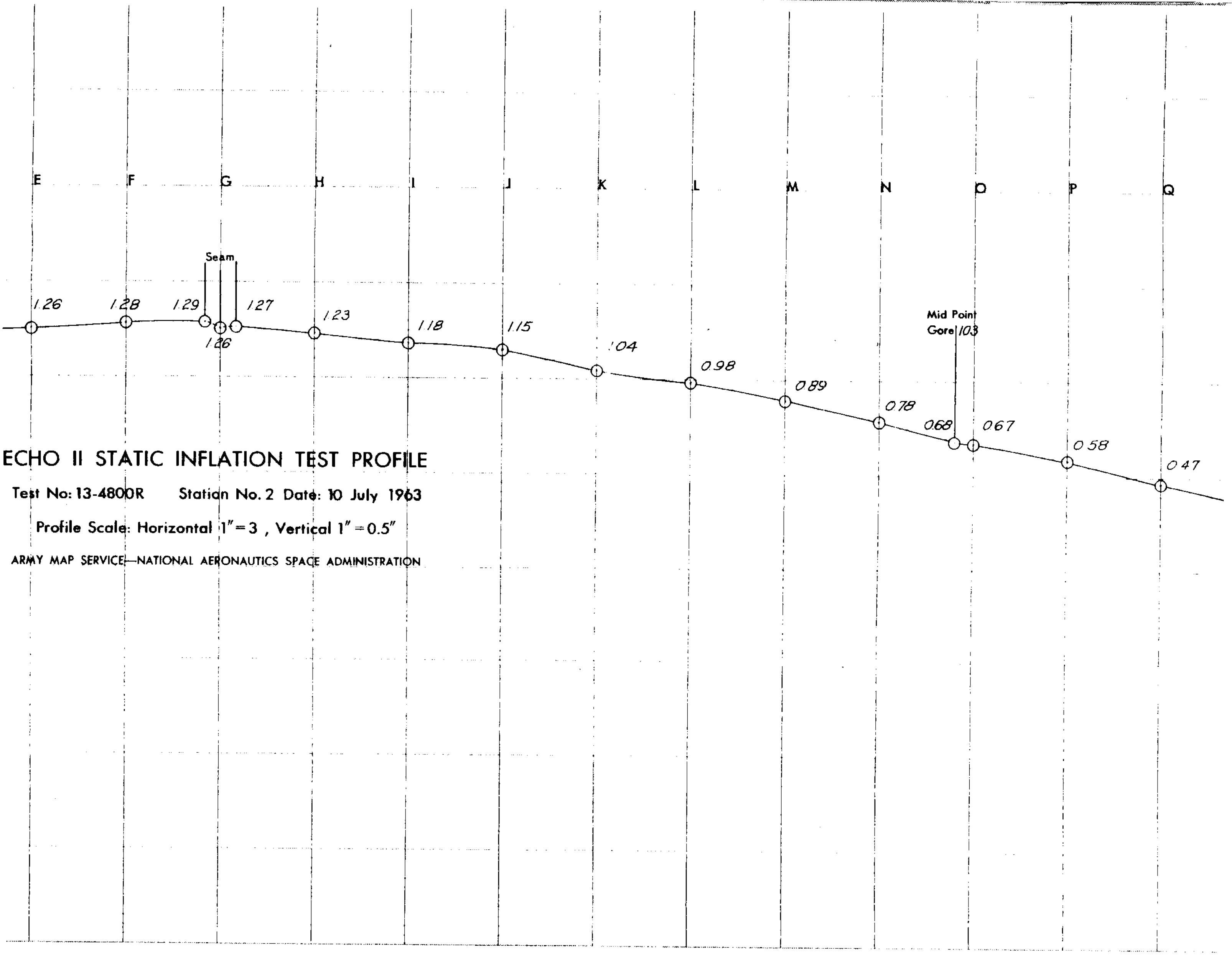


FIGURE 10


QQ
RR
SS
TT
UU
VV
WW
XX
YY
ZZ
A
B
C
D
Seam
Level Point
0.08
0.16
0.30
0.47
0.58
0.71
0.82
0.94
Mid Point
Gore 1.02
0.95
1.05
1.11
1.17
1.22
1.24



ECHO II STATIC INFLATION TEST PROFILE

Test No: 13-4800R Station No. 2 Date: 10 July 1963

Profile Scale: Horizontal 1" = 3 , Vertical 1" = 0.5"

ARMY MAP SERVICE—NATIONAL AERONAUTICS SPACE ADMINISTRATION

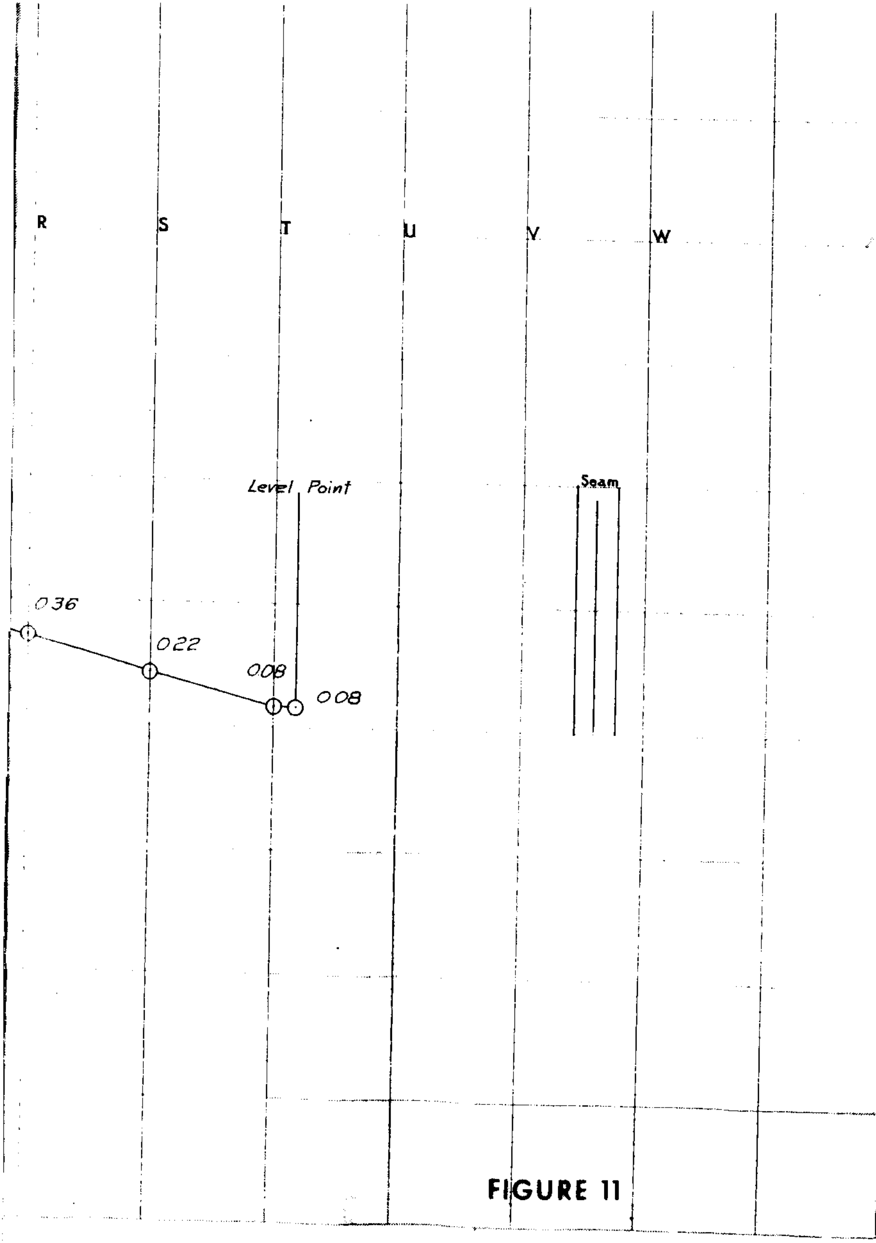
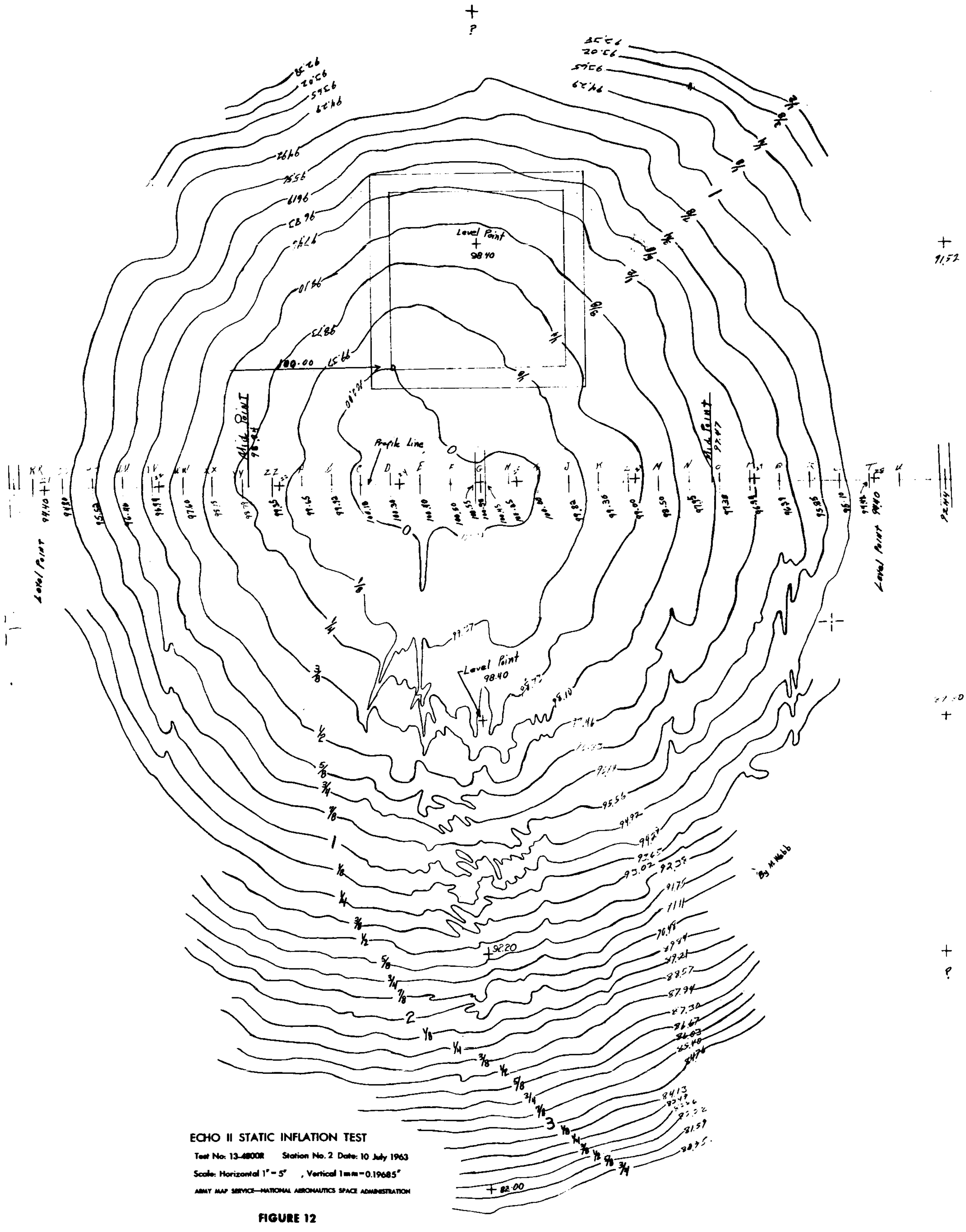


FIGURE 11



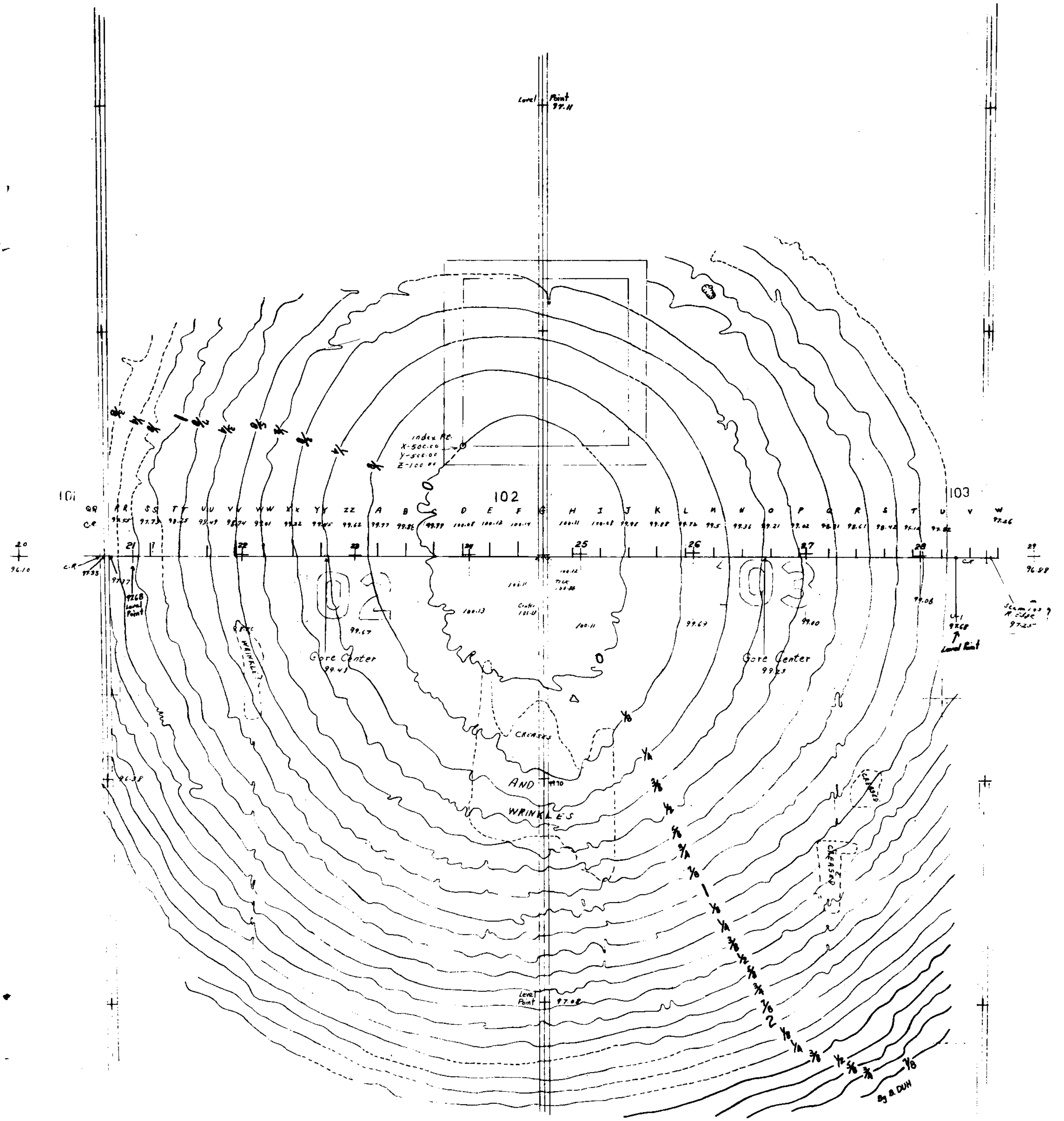
ECHO II STATIC INFLATION TEST

Test No: 13-4800R Station No. 2 Date: 10 July 1963

Scale: Horizontal 1" = 5" , Vertical 1mm = 0.19685"

ARMY MAP SERVICE—NATIONAL AERONAUTICS SPACE ADMINISTRATION

FIGURE 12



ECHO II STATIC INFLATION TEST

Test No: 13-7400R Station No. 2 Date: 10 July 1963

Scale: Horizontal 1" = 5', Vertical 1mm = 0.4926"

ARMY MAP SERVICE—NATIONAL AERONAUTICS SPACE ADMINISTRATION

FIGURE 13